Modeling Nitrogen and Phosphorus Transport in Vadose Zone using HYDRUS- 1D

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Abstract

The application of large manure on the agricultural lands that derived from the Concentrated Animal Feeding Operations (CAFOs) could cause excess nutrients such as nitrogen and phosphorus transport to the groundwater through vadose (unsaturated) zone. The objective of this study is as follows: (1) to compare nitrogen and phosphorus transport in the vadose zone at different Land Management Units (LMUs) for three consecutive years (2004-06) using HYDRUS-1D, and (2) to analyze the sensitivity of nitrogen and phosphorus transport in different soil types on the van Genuchten soil hydraulic parameters: saturated water content (θs), residual water content (θr), alpha and n parameters, saturated hydraulic conductivity (Ks), adsorption isoterm coefficients (Kd and β), and tortuosity parameter (l). After modeling using HYDRUS-1D, it could be concluded that the transport of nitrogen was faster during the wet year. The concentrations of nitrogen compounds were most sensitive to saturated water content (θs). Phosphorus was most sensitive to adsorption isoterm coefficient (Kd).

Keywords: CAFO(s), HYDRUS-1D, LMU(s), nitrogen, phosphorus, vadose zone

Pemodelan Transpor Nitrogen dan Fosfor pada Zona Tidak Jenuh Air dengan Menggunakan HYDRUS- 1D

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Abstrak

Pemakaian kotoran ternak dalam jumlah besar pada lahan-lahan pertanian yang berasal dari Peternakan Terkonsentrasi dapat mengakibatkan kelebihan unsur seperti nitrogen dan fosfor yang bertranspor menuju air tanah melalui zona tidak jenuh air. Tujuan penelitian ini adalah sebagai berikut: (1) untuk membandingkan transpor nitrogen dan fosfor di daerah tidak jenuh air pada unit lahan pertanian yang berbeda selama tiga tahun berturut-turut (2004-06) dengan menggunakan HYDRUS-1D, dan (2) untuk menganalisa sensitivitas transpor nitrogen dan fosfor pada jenis tanah yang berbeda dengan menggunakan parameter hidrolik tanah van Genuchten: kandungan air jenuh (θs), kandungan air residual (θr), parameter alpha dan n, konduktivitas hidrolik jenuh (Ks), koefisien adsorpsi isoterm (Kd dan β), dan parameter tortuositas (l). Setelah pemodelan dengan menggunakan HYDRUS-1D, dapat disimpulkan bahwa transpor nitrogen lebih cepat selama tahun basah. Konsentrasi nitrogen paling sensitif terhadap kandungan air jenuh (θs). Fosfor paling sensitif terhadap koefisien adsorpsi isoterm (Kd).

Kata Kunci: Peternakan Terkonsentrasi, HYDRUS-1D, Satuan Lahan Pertanian, nitrogen, fosfor, zona tidak jenuh air

I. INTRODUCTION

The application of large manure on the agricultural lands that derived from the Concentrated Animal Feeding Operations (CAFOs) could cause excess nutrients such as nitrogen and phosphorus transport to the groundwater through vadose (unsaturated) zone. Due to nitrate pollution that contaminates the groundwater has become a particular concern. Therefore, it is important to know how nitrogen and phosphorus transport in the vadose zone.

Many studies have focused on phosphorus transport in the surface runoff and only a few have shown phosphorus transport that could occur in the vadose zone (Algoazany et al., 2007). Phosphorus transport through vadose zone is small and often neglected due to its slow mobility in the soils (Baker et al., 1975; Sharpley et al.,1993; Sims et al., 1998; Heathwaite and Dils, 2000; Hansen et al., 2002). Phosphorus transport through vadose zone is not considered as an important source of phosphorus movement to the groundwater (Sims et al., 1998; Hansen et al., 2002).

The objective of this study is as follows:

1. to compare nitrogen and phosphorus transport in the vadose zone at different Land Management Units (LMUs) for three consecutive years (2004-06) using HYDRUS-1D.
2. to analyze the sensitivity of nitrogen and phosphorus transport in different soil types on the van Genutchten soil hydraulic parameters: saturated water content (θs), residual water content (θr), alpha and n parameters, saturated hydraulic conductivity (Ks), adsorption isoterm coefficients (*Kd* and β), and tortuosity parameter (l).

II. LITERATURE REVIEW

Factors that affect nitrogen and phosphorus transport in the vadose zone can be divided into two factor; external and internal factors.

The external factors are:

1. N and P application rate
2. Time and method of application
3. Rainfall timing and intensity

Culley et. al, 1983; Edwards and Daniel, 1993; Sharpley et. al, 1993, 1994).

The internal factors are:

1. N and P chemistry
2. Soil type and structure
3. Preferential flow path
4. Organic matter content

(Sharpley et. al, 1993; Sims et.al, 1998; Gilliam et. al, 1999; Hansen et. al, 2002).

2.1 Basic approaches to modeling nitrogen and phosphorus transport in the vadose zone

HYDRUS-1D is a one dimensional model to simulate vertical flow and solute transport in variably saturated soils under both steady-state and transient conditions (Šimůnek et al., 2008). In the vadose zone, lateral water fluxes can be assumed to be negligible and vertical flow dominates. Vertical flow and solute transport are described based on Richards equation and advection – dispersion equation.

2.2 Model approaches for Nitrogen and Phosphorus

Source Strength – the concentration of solute; Advection – movement of the solute in the direction of groundwater flow in accordance with Darcy's Law; Dispersion – spreading of solute due to microscopic scale variations in flow and to molecular diffusion; Adsorption – reduction of solute in the groundwater caused by sorption of the species on to the soil; Decay – reduction of solute with time due to biological degradation, chemical reaction or radioactive decay (Freeze, 1989).

The forms of N in the soil, known as *Chain Reaction*: Ammonia (NH4)—>Nitrite (NO2) —>Nitrate (NO3). The forms of P in the soil: dissolved and particulate, inorganic and organic. Dissolved inorganic P is considered in the leaching progress. Particulate organic P is *not* considered due to their complexities.

III. METHODOLOGY

3.1 Study Area

The study area consisted of two counties in Texas. Each county had one big dairy, approximately 100.000 cows, known as CAFO (Concentrated Animal Feeding Operations). Table 1 and 2 described Land Management Unit (LMU)s with source of nitrogen that derived from wastewater and manure.

3.2 Data

1. Manure and wastewater records from two different dairies, one was in Deaf Smith County and the other one was in Erath County; and
2. Meteorological data for 2004-06 from Hereford and Stephenville Station (NRCS, 2008).

3.2.1 Precipitation

Precipitation for 3 (three) consecutive years (2006-08) is shown in Figure 1 and 2 for Deaf Smith County and Erath County.

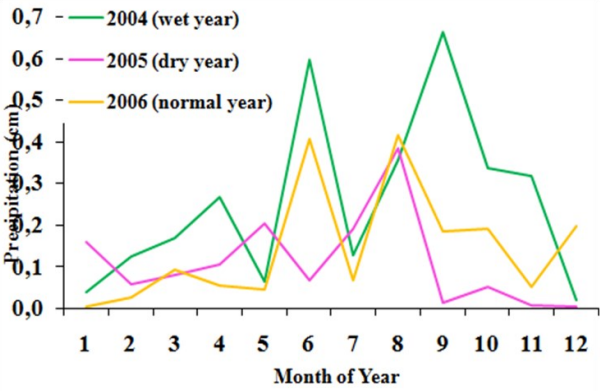


Figure 1. Precipitation in Deaf Smith County

Tabel 1. Description of a dairy in Deaf Smith County, Panhandle, TX

No	Land Management Unit (LMU)	Area (acre)	Source of Nitrogen	Crop
1	3	125	wastewater	wheat - corn silage
2	4	96	wastewater	corn silage - wheat
3	5a	440	wastewater	wheat – sorghum silage - wheat
4	5b	440	wastewater	wheat
5	5c	200	manure	bare soil
6	6a	440	wastewater	alfalfa
7	6b	220	wastewater	wheat

Tabel 2. Description of a dairy in Erath County, TX

No	Land Management Unit (LMU)	Area (acre)	Source of Nitrogen	Crop
1	1	57	wastewater	coastal Bermuda grass
2	2	83	manure	bare soil
3	3a	65	manure	bare soil
4	3b	65	wastewater	coastal Bermuda grass
5	7	88	manure	bare soil
6	8	92	manure	bare soil
7	9	68	manure	bare soil

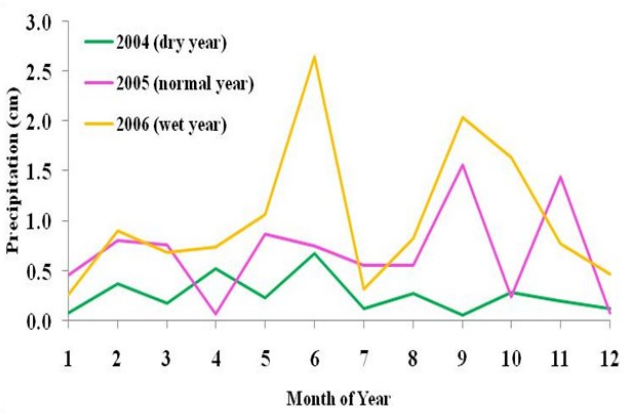


Figure 2. Precipitation in Erath County

3.2.3 Soil Layers

Soil layers in both counties as described in Figure 3. Each soil layer had 200 cm in depth. The soil layers in Deaf Smith County, consisted of clay loam, clay, and clay loam, whereas in Erath Smith County, consisted of sandy loam, clay, clay loam, and sandy loam.

(a) (b)

Figure 3. Soil Layers in (a) Deaf Smith County and (b) Erath County

3.2.4 HYDRUS-1D Model

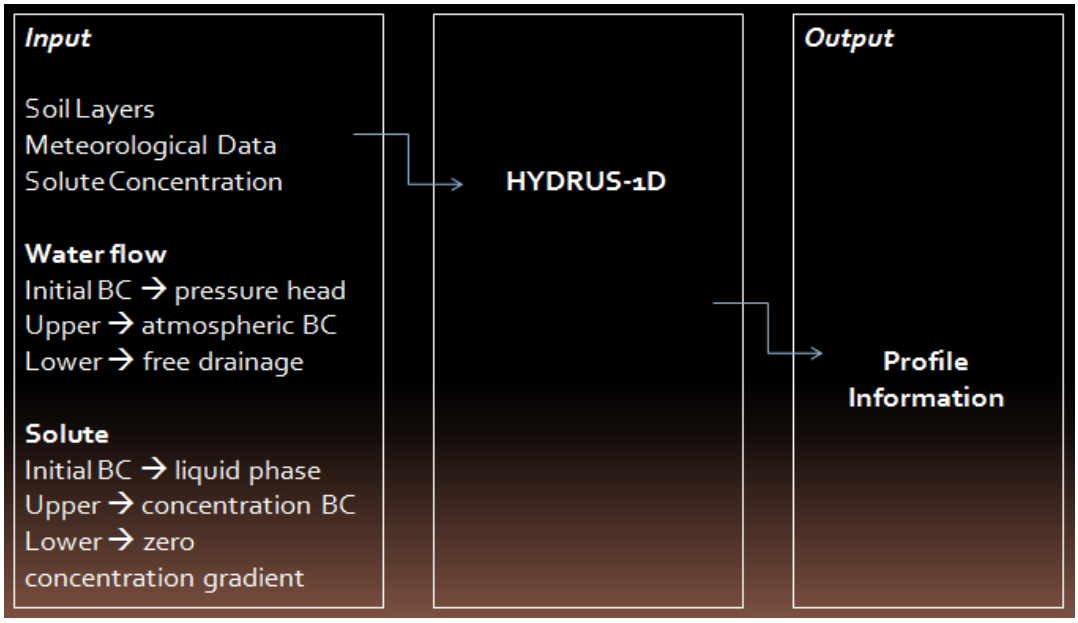


Figure 4. Modeling Nitrogen and Phosphorus using HYDRUS-1D

Figure 4. showed the inputs to model nitrogen and phosphorus using HYDRUS-1D. There were soil layers, water flow, and solute. The output was the profile information.

IV. RESULTS AND DISCUSSIONS

4.1 Nitrogen Transport

Nitrogen concentrations for the dry year were less compared to concentrations for wet and normal years. These results were observed for both Deaf Smith and Erath counties. During the wet year, nitrogen transport in soil was found to be much faster. The liquid manure (wastewater) had given much more nitrate leaching than the dry manure. Nitrogen transport for dry and wet years was shown in Table 1 and nitrogen transport that derived from dry manure and wastewater described in Table 2.

Table 1. Nitrogen Transport in dry and wet years

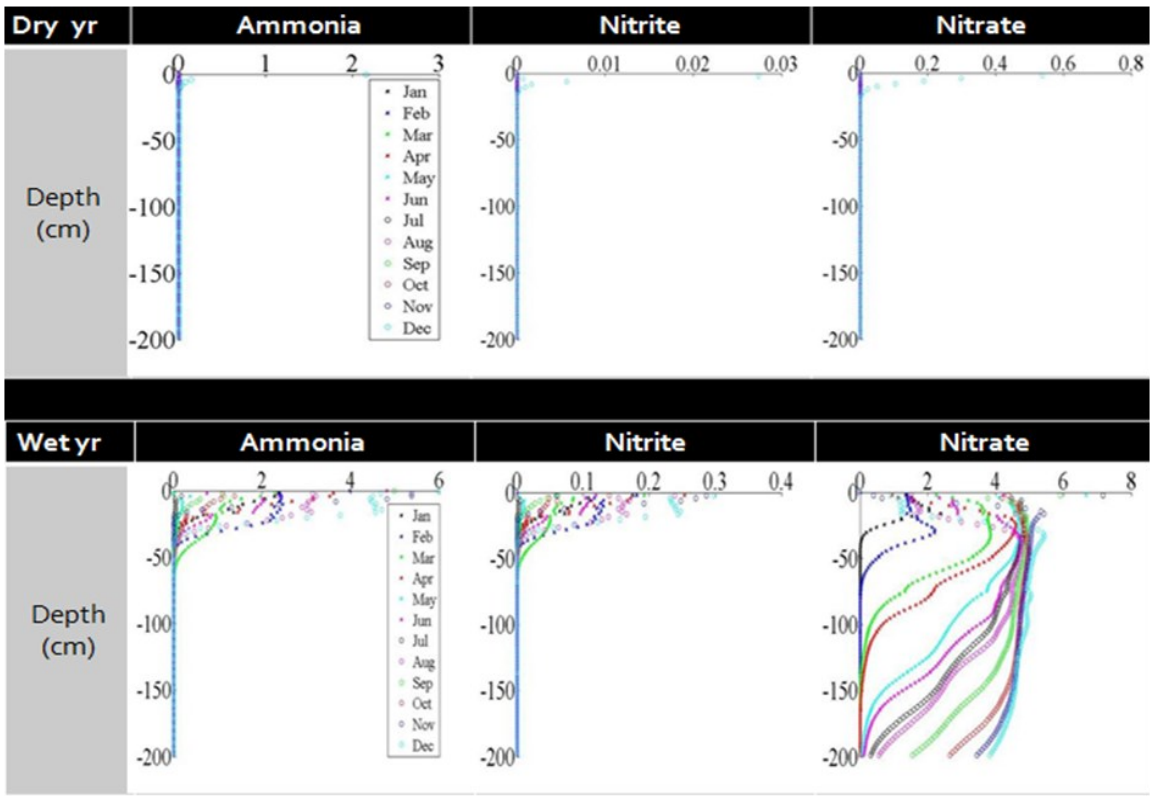
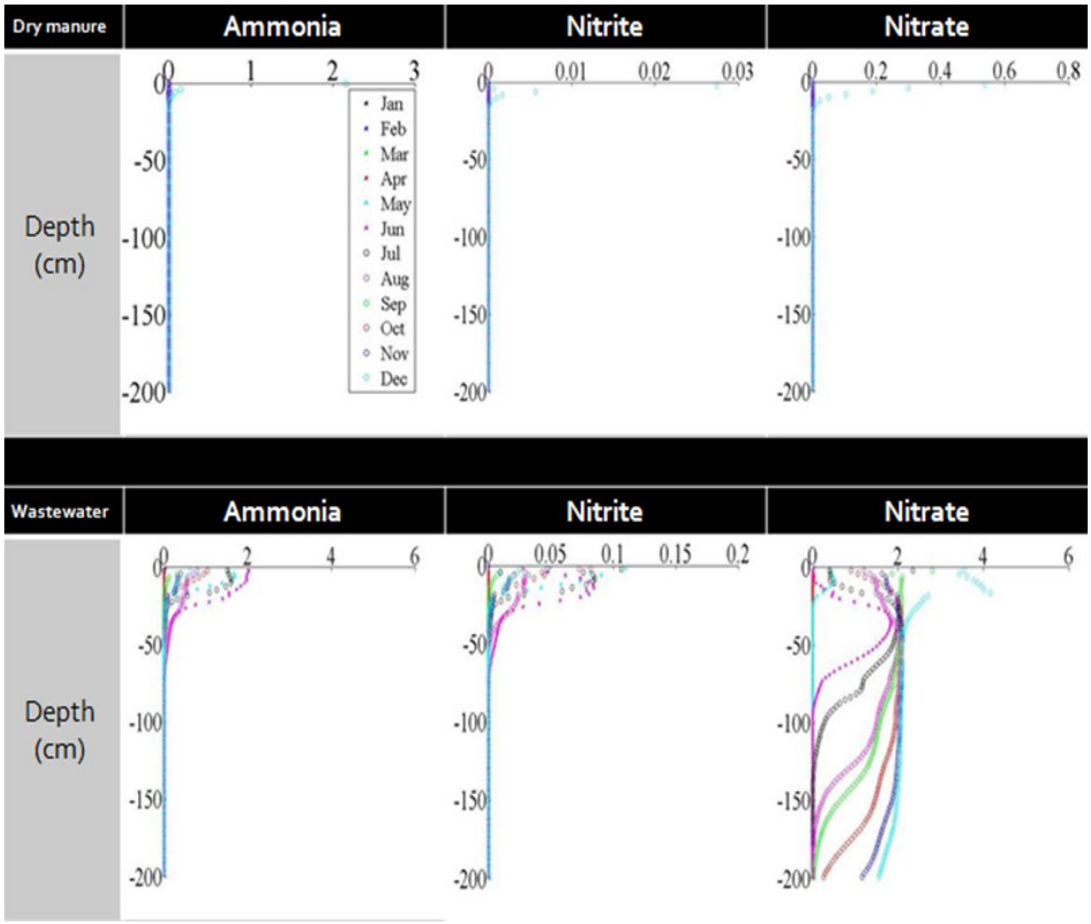
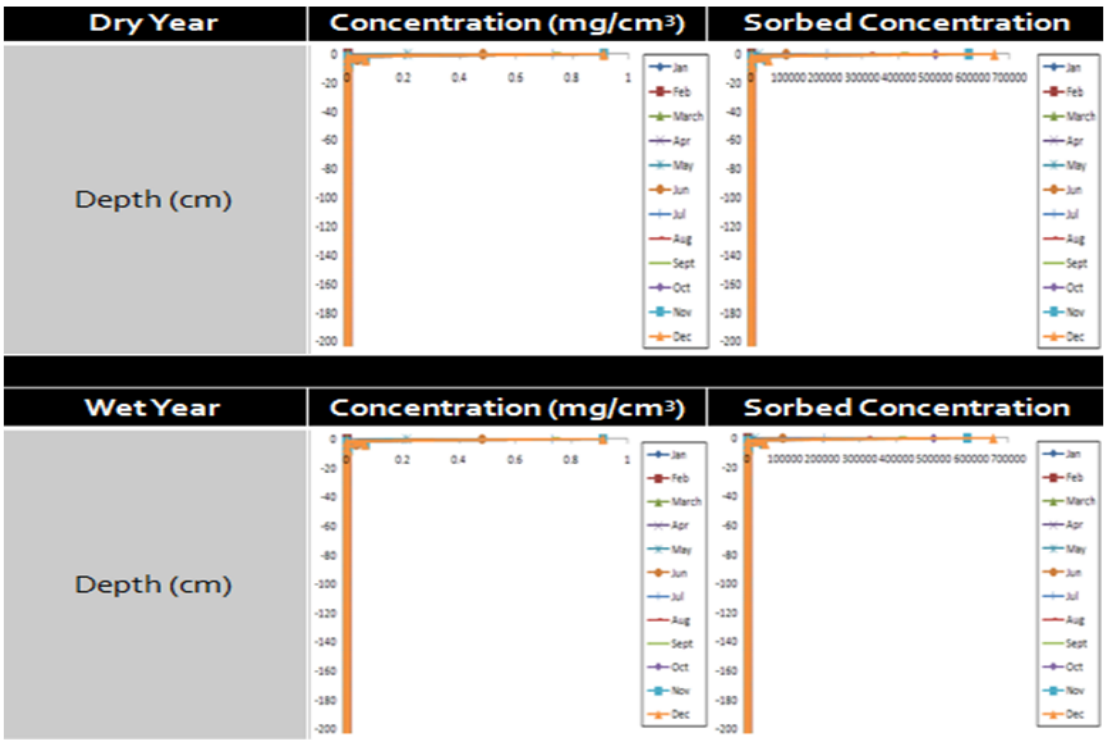


Table 2. Nitrogen Transport derived from dry manure and wastewater



4.2 Phosphorus Transport

Table 3. Phosphorus Transport in dry and wet years



The leaching process of dissolved inorganic phosphorus concentrations for the dry year were less compared to concentrations for wet and normal years. These results were observed for both Deaf Smith County and Erath County (Table 3).

4.3 Sensitivity Analysis

The concentration of nitrogen compounds and was most sensitive to saturated water content (θs). By increasing 20%, the transport of nitrogen compounds was slower due to saturated condition (air entrapment). By decreasing 20%, the transport of nitrogen compounds was faster. Phosphorus was most sensitive to adsorption isoterm coefficient (*Kd*).

V. CONCLUSIONS

The conclusion of this study is as follows:

1. The transport of nitrogen was faster during the wet year.
2. The concentrations of nitrogen compounds were most sensitive to saturated water content (θs).
3. Phosphorus was most sensitive to adsorption isoterm coefficient (*Kd*).

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